The benefits achieved by utilization of swirl ports **124** are discussed in the cited application Ser. No. 08/800,189.

From swirl chamber **122**, gas flow is through equiangularly spaced swirl ports **126** in partition wall section **108** into an annular chamber **128**. Swirl ports **130** in cylindrical wall **16** permit gas flow from annular chamber **128** into an annular plenum chamber **132** provided between an outer cylindrical shell **134** and cylindrical wall **16**. Preferably, a ring **135** of porous media of suitable heat exchanging material, such as braided steel mesh screens, is positioned in plenum chamber **132**, which the gases flow through and are cooled en route to a plurality of vent holes **136** in shell **134** leading to the airbag **12**.

It will be apparent to those skilled in the art that various modifications and variations may be made to the vehicle occupant restraint apparatus of the present invention without departing from the spirt of the invention. For example, the damper fluid may comprise an electro-rheological fluid whose viscosity is controlled by an electric field to vary flow rate through orifice **92** and thus the damping force exerted against the rearward stroke of regenerative pumping piston **30**. It will also occur to those skilled in the art that, rather than a rheological hydraulic fluid, the desired modulated damping of the piston's regenerative pumping stroke could be achieved by varying the opening area of orifice **92**, such as to vary the flow rate of a conventional hydraulic damping fluid through the orifice. Thus, it is intended that the scope of the present invention cover modifications and variations thereof, provided they come within the spirt of the appended claims and thus equivalents.

We claim:

1. An occupant restraint apparatus for installation in a vehicle, comprising:

an airbag; and

an inflator including:

a combustion chamber in fluid communication with the airbag;

a reservoir containing a liquid propellant;

a port fluidically interconnecting the combustion chamber and the liquid propellant reservoir;

an inflation initiator operable, in response to an accident involving the vehicle, to pressurize the liquid propellant reservoir, such that the liquid propellant is injected through the port into the combustion chamber for ignition and generation of combustion gases to inflate the airbag;

a sensor for generating a signal indicative of an accident parameter; and

an inflation rate modulator controlling the inflation initiator and, thereafter, varying a combustion rate of the liquid propellant in the combustion chamber in accordance with the sensor signal, thereby regulating an inflation rate of the airbag.

2. The apparatus of claim **1**, further comprising a piston separating the combustion chamber and the reservoir, the piston executing a pumping stroke to inject the liquid propellant through the port into the combustion chamber, the inflation rate modulator acting to vary a pumping stroke rate of the piston that determines the combustion rate.

3. The apparatus of claim **2**, further comprising a damping chamber containing a hydraulic fluid for developing a damping force retarding the piston pumping stroke, the inflation rate modulator acting to vary the damping force.

4. The apparatus of claim **3**, wherein the hydraulic fluid is a rheological fluid and the inflation rate modulator acts to vary a viscosity of the rheological fluid.

5. The apparatus of claim **4**, wherein the damping chamber includes an orifice through which the rheological fluid is pumped by the piston pumping stroke at a rate determined by the rheological fluid viscosity.

6. The apparatus of claim **5**, wherein the rheological fluid is a magneto-rheological fluid, and the inflation rate modulator further comprises an electromagnet for producing a magnetic field proximate the orifice to control the viscosity of the magneto-rheological fluid according to electromagnet current excitation by the inflation rate modulator.

7. The apparatus of claim **6**, wherein the sensor includes a plurality of sensors for producing signals respectively indicative of occupant and collision parameters, and the inflation rate modulator includes a central processing unit programmed to process the sensor signals, such as to determine a modulation of electromagnet current excitation during inflation of the airbag.

8. The apparatus of claim **6**, wherein the piston includes a first piston head separating the liquid propellant reservoir and the combustion chamber and a second piston head acting on the magneto-rheological fluid in the damping chamber.

9. The apparatus of claim **8**, wherein the injection port is defined in part by a hole through the first piston head.

10. The apparatus of claim **9**, wherein the injection port is further defined by a forwardly extending needle valve element projecting through the hole to control an opening area of the injection port.

11. The apparatus of claim **10**, wherein the needle valve element includes a terminal portion disposed in fluid-sealing relation with the hole before operation of the inflation initiator.

12. The apparatus of claim **11**, wherein the needle valve element includes angularly spaced, longitudinally extending, peripheral surface grooves defining a differential opening area of the injection port during the pumping stroke of the piston.

13. The apparatus of claim **11**, wherein the needle valve element is of a tubular shape to accommodate a squib at a rearward end and a forwardly extending cavity accommodating a booster charge of the inflation initiator, the terminal portion of the needle valve element including a frangibly sealed opening into the combustion chamber.

14. An airbag inflator comprising:

a housing;

a combustion chamber provided in the housing;

a reservoir provided in the housing for containing a liquid propellant;

a piston slidingly received in the housing and having a first piston head separating the combustion chamber from the liquid propellant reservoir;

an injection port;

a pyrotechnic initiator, detonated in response to a vehicle accident, to pressurize the combustion chamber and to ignite liquid propellant injected into the combustion chamber from the reservoir through the injection port during a regenerative pumping stroke of the piston, combustion of the injected liquid propellant producing airbag inflation gasses; and

a controller varying a rate of the piston's regenerative pumping stroke according to at least one accident parameter, thereby regulating a rate of airbag inflation during airbag deployment.

15. The airbag inflator of claim **14**, wherein the controller includes a hydraulic damper for exerting a variable retarding force on the piston's regenerative pumping stroke.

16. The airbag inflator of claim **15**, wherein the hydraulic damper includes a damping chamber containing a hydraulic

fluid, and the piston includes a second piston head slidingly received in the damping chamber.

17. The airbag inflator of claim **16**, wherein the damping chamber further includes an orifice through which the hydraulic fluid is expelled by the second piston head during the piston's regenerative pumping stroke, the controller acting to adjustably control a rate of hydraulic fluid flow through the orifice.

18. The airbag inflator of claim **17**, wherein the hydraulic fluid is a rheological fluid.

19. The airbag inflator of claim **18**, wherein the hydraulic fluid is a magneto-rheological fluid, and the controller further includes an electromagnet for generating a magnetic field to vary a viscosity of the magneto-rheological fluid flowing through the orifice.

20. The airbag inflator of claim **19**, wherein the controller further includes;

a plurality of sensors for generating signals respectively indicative of occupant and collision parameters, and

a central processing unit for processing the sensor signals to variably modulate current excitation of the electromagnet.

21. The airbag inflator of claim **19**, further including a containment chamber for recovering the magneto-rheologically fluid expelled through the orifice.

22. The airbag inflator of claim **21**, wherein the damping and containment chambers are concentrically arranged in the housing, and the second piston head is of an annular configuration and connected to the first piston head by a cylindrical skirt.

23. The airbag inflator of claim **22**, wherein the containment chamber includes a vent open to atmospheric pressure, and an annular piston slidingly received in the containment chamber between the orifice and the vent.

24. The apparatus of claim **17**, wherein the injection port is defined in part by a hole through the first piston head.

25. The apparatus of claim **24**, wherein the injection port is further defined by a forwardly extending needle valve element projecting through the hole to control an opening area of the injection port.

26. The apparatus of claim **25**, wherein the needle valve element includes a terminal portion disposed in fluid-sealing relation with the hole prior to detonation of the pyrotechnic initiator.

27. The apparatus of claim **26**, wherein the needle valve element includes angularly spaced, longitudinally extending, peripheral surface grooves defining a differential opening area of the injection port during the regenerative pumping stroke of the piston.

28. The apparatus of claim **27**, wherein the needle valve element is of a tubular shape accommodating a squib at a rearward end and a forwardly extending cavity accommodating a booster charge of the pyrotechnic initiator, the terminal portion of the needle valve element including an opening from the booster charge cavity into the combustion chamber, the opening normally closed by a frangible seal.

29. The airbag inflator of claim **28**, wherein the hydraulic fluid is a rheological fluid.

30. The airbag inflator of claim **29**, wherein the hydraulic fluid is a magneto-rheological fluid, and the controller further includes an electromagnet for generating a magnetic field to vary a viscosity of the magneto-rheological fluid flowing through the orifice.

31. The airbag inflator of claim **30**, wherein the controller further includes;

a plurality of sensors for generating signals respectively indicative of occupant and collision parameters, and

a central processing unit for processing the sensor signals to variably modulate current excitation of the electromagnet.

32. An airbag inflator comprising:

a housing;

a combustion chamber provided in the housing;

a reservoir provided in the housing for containing combustible fluid;

a piston slidingly received in the housing and having a first piston head separating the combustion chamber from the combustible fluid reservoir;

an injection port;

a initiator, activated in response to a vehicle accident, to pressurize the combustion chamber and to ignite combustible fluid injected into the combustion chamber from the reservoir through the injection port during a regenerative pumping stroke of the piston, combustion of the injected combustible fluid producing airbag inflation gasses; and

a controller including at least one sensor, the controller varying a rate of the piston's regenerative pumping stroke according to at least one accident parameter, thereby regulating a rate of airbag inflation during airbag deployment.

33. The airbag inflator of claim **32**, wherein the controller further includes a hydraulic damper for exerting a variable retarding force on the piston's regenerative pumping stroke.

34. The airbag inflator of claim **33**, wherein the hydraulic damper further includes a damping chamber containing hydraulic fluid, and the piston includes a second piston head slidingly received in the damping chamber.

35. The airbag inflator of claim **34**, wherein the damping chamber further includes an orifice through which the hydraulic fluid is expelled by the second piston head during the piston's regenerative pumping stroke, the controller acting to adjustably control a rate of hydraulic fluid flow through the orifice.

36. The airbag inflator of claim **35**, wherein the hydraulic fluid is a rheological fluid.

37. The airbag inflator of claim **36**, wherein the hydraulic fluid is a magneto-rheological fluid, and the controller further includes an electromagnet for generating a magnetic field to vary viscosity of the magneto-rheological fluid flowing through the orifice.

38. The airbag inflator of claim **37**, wherein the controller further includes;

a plurality of sensors for generating signals respectively indicative of occupant and collision parameters, and

a central processing unit for processing the sensor signals to variably modulate current excitation of the electromagnet.

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